C. Laser Surface Texturing of Seal Faces

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Contractor: Argonne National Laboratory
Contract No.: W-31-109-ENG-38

Objective

- Evaluate friction and wear performance of laser-textured surfaces.
- Identify candidate components and evaluate performance of laser-textured surfaces for specific applications.
- Optimize laser microdimple size, depth, and density to achieve maximum performance.
- Explore the effects of super-low-friction coatings on performance of dimpled surfaces.

Approach

- Apply laser texturing to water pump face seals of SiC ceramic and evaluate the performance in an instrumented seal tester.
- Conduct oil-lubricated friction and wear tests for laser-textured steel surfaces for both conformal and nonconformal contacts by using both unidirectional and reciprocating sliding.
- Combine near-frictionless carbon (NFC) coatings and other low-friction and wear-resistant coatings with laser surface texturing (LST) for synergistic effects in both ceramic seal and oil-lubricated steel contacts.

Accomplishments

- Characterized size, depth, shape, and density of microdimples on SiC face seals and steel samples by using three-dimensional (3D) microsurface optical profilometry and electron microscopy.
- Determined from seal test results that laser-dimpled surfaces reduced frictional torque by 40 to 60%, depending on face pressure and other test conditions.
- Found that laser-dimpled SiC seal surfaces showed some wear marks, especially after tests under high face pressures.
- Found that, under unidirectional conformal contact sliding, LST reduced the friction coefficient of lubricated steel surfaces substantially, especially under boundary and mixed lubrication regimes.

- Found that LST expanded the range of operating contact parameters for the hydrodynamic lubrication regime to lower speeds and higher loads.

Future Direction

- Characterize the effect of the laser-texturing process on changes to the microstructure and properties in the vicinity of dimples for ceramic (SiC) and steel materials.
- Optimize the dimple parameter for various lubrication regimes and for various seal and engine component applications.
- Combine LST technology with low-friction and superhard coatings for maximum reduction in friction and wear in ceramic face seals and oil-lubricated steel engine components.

Introduction

SurTech Ltd. has developed a laser surface texturing (LST) technology that enhances the overall tribological performance of lubricated sliding and rotating surfaces. This technology involves creation of microdimples (100 μm diam and about 10 μm deep) having a regular pattern applied on a given surface by a pulsating laser beam. Under hydrodynamic lubrication, and in the conformal contact configuration, microdimples on the contact surfaces can lower friction coefficients and may reduce wear. Under oil- or water-lubricated conditions, shallow dimples can serve as reservoirs for oil or water and thus increase the hydrodynamic lubrication efficiency of these surfaces. This low-friction technology has the potential for application in various engine components, such as the interface between the face seal and cylinder liner piston ring.

The main objective of this project is to produce well-controlled dimples on sliding and rotating conformal surfaces and to evaluate their tribological performance under the wide range of conditions typically found in engines and rotating equipment. At this initial phase, the tribological evaluation will focus primarily on rotating face seals and lubricated engine components. The issue of the durability of the dimples and possible optimization of dimple size, depth, and pattern for various lubrication regimes is also being investigated. Furthermore, potential beneficial effects of soft and hard overcoats having superhard and low-friction properties are also being explored.

In FY 2003, efforts at Argonne National Laboratory were devoted to evaluating LST for water pump seals and oil lubrication of steel surfaces. Several SiC face seals and rectangular steel samples were laser-textured with microdimples by Surtech Ltd. Dimpled samples were returned to Argonne for characterization and testing. Some of the seals were tested at Argonne in a mechanical face-seal test machine for wear studies, while a few of the dimpled seals were sent to Western Michigan University for high-precision torque measurements. Argonne has also worked on the application of NFC coatings on a few of the seals to further enhance their friction and wear performance. The textured steel samples were all tested at Argonne.

Results

Seal Tests

In a series of seal tests, Argonne investigated the wear behavior of dimpled SiC seal surfaces. Figure 1 shows a 3D image of a dimpled SiC face seal. As is clear in the figure, the dimples are produced in a geometric array, and they are typically 4 to 5 μm deep and about 100 μm in diameter.

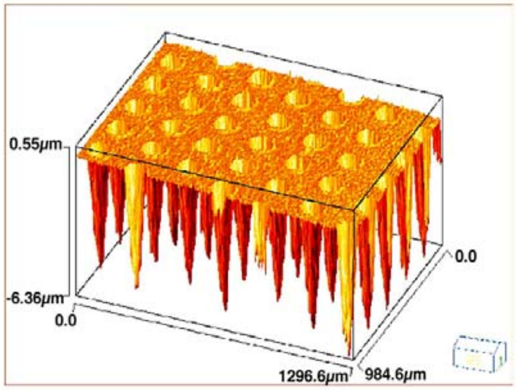

Figure 1. 3D image of laser-dimpled SiC seal face.

After undergoing wear tests on the dimpled surfaces at face pressures of up to 50 psi, the dimples remained mostly intact, but at much higher face pressures, some wear marks were observed, especially at or near the center of the wear tracks (as shown in Figure 2).

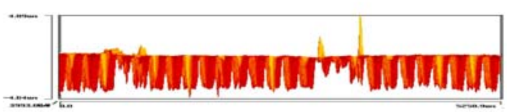

Figure 2. Laser-textured surface after wear test at 100-psi face pressure.

The depth of wear groove is about 1 µm. Also, some of the dimples appeared to have been filled with wear debris particles, as evident from Figure 2.

Torque measurements of laser-dimpled seals were performed at Western Michigan University in a highly instrumented seal test machine. These tests involved two control seals of directly sintered silicon carbide with standard production lapped surfaces and two laser-dimpled seals.

During these tests, two repeat tests on control rings showed similar performance, indicating that the test protocol was highly reproducible and reliable. One of the results from these tests is presented in Figure 3. Likewise, the two laser-dimpled rings also performed comparably well. Figure 4 shows the test results from one of those rings. The start-up and changes under pressure during tests often cause some instability in operation, as evidenced by rises in both the torque signal and seal face temperature. This is usually a short term situation and is commonly seen in the operation of all conventional seals. However, the laser dimpled rings had torque values significantly lower than those of the control rings at the same operating pressures, indicating that laser texturing had a positive impact on the performance of SiC seals. A slight reduction in face temperature was also noted for the laser-dimpled seal faces.

After the torque measurements were taken, wear of rotating surfaces was also investigated with a 3D surface profilometer. The results of these studies are summarized in Table 1. As is clear in the data, the wear of laser-dimpled seal faces is slightly higher than that of the control seal. The higher insert wear may have been due to the rougher surface finish of the dimpled seals.

Lubricated Steel Test

Unidirectional sliding tests were conducted on oil-lubricated seals with a commercially available test rig (CSEM) in the standard pin-on-disc contact configuration. The "pin" consisted of a 9.55-mm-diam hardened 52100 steel ball with a nominal hardness of 60 Rc, on which a 4.7-mm-diam flat area was created by grinding. This results in a conformal contact interface with the rotating disc, as shown schematically in Figure 5. The 50-mm-diam, 10-mm-thick disc samples are made of hardened H-13 steel and also have a nominal hardness of 60 Rc. Tests were conducted with disc samples that had ground, polished, and dimpled surfaces. Tests were conducted with normal loads of 2, 5, 10, and 20 N and sliding speeds of 0.015 and 0.75 m/s. All the discs were lubricated

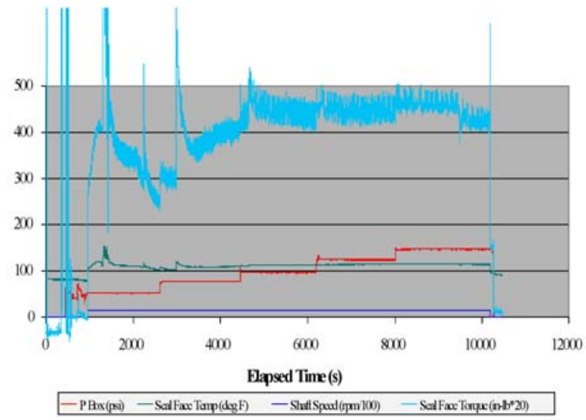

Figure 3. Seal face temperature and torque as a function of time for an untreated (control) seal. The torque signal was multiplied by 20 to show it more effectively on the same axis as chamber pressure and seal face temperature. The tachometer reading was divided by 100, so the operating shaft speed (1800 rpm) shows as 18.

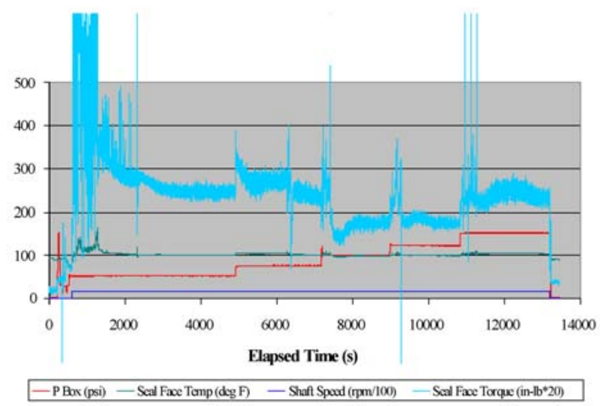

Figure 4. Seal face temperature and torque as a function of time for laser-dimpled seal, verifying significant reduction in torque. The torque signal was multiplied by 20 to show it more effectively on the same axis as chamber pressure and seal face temperature. The tachometer reading was divided by 100, so the operating shaft speed (1800 rpm) shows as 18.

Table 1. Depth of wear in control and laser-dimpled seal faces and counterface inserts

SiC ring	Insert no.	Ring wear, µm	Insert wear, µm	Comments
Control	1	0.55	0.20	Insert shows some roughening across much of the wear track. Band ~1 mm wide at ID shows the most overall wear. Ring shows overall wear of the contact area
Laser dimpled	2	0.71	1.26	Insert appears slightly roughened over entire contact area. Typical wear pattern shows 1-mm band of overall wear at ID. Ring wear pattern is typical; maximum wear at ID of wear track

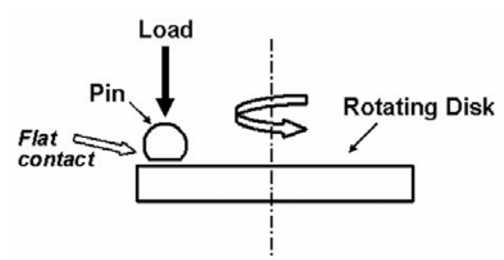

Figure 5. Schematic diagram of lubricated pin-on-disc contact configuration.

with a polyalphaoletin-based commercial engine oil. The test procedure consisted of starting each test at the low speed of 0.015 m/s and a constant load. The sliding speed was increased in 0.05-m/s steps after 3 min at each speed. The test protocol ensured that each test contact started in the boundary lubrication regime but moved into the mixed and finally the hydrodynamic lubrication regime as sliding speed increased.

The variation of friction coefficient with time and hence sliding speed for a typical test is shown in Figure 6. The friction behavior in the test with the ground disc shows the classic Streibeck curve, in which the friction coefficient under the boundary lubrication regime is high, with a typical value of about 0.12. As the sliding speed increases, the oil film thickness also increases. After about 180 s, the ratio between oil film thickness and composite surface roughness [the so-called lambda (λ) ratio] moves the contact into the mixed-lubrication regime, with a concomitant reduction in friction. At much higher speeds, the oil film thickness is high enough to completely separate the sliding surface, and hydrodynamic lubrication is in effect.

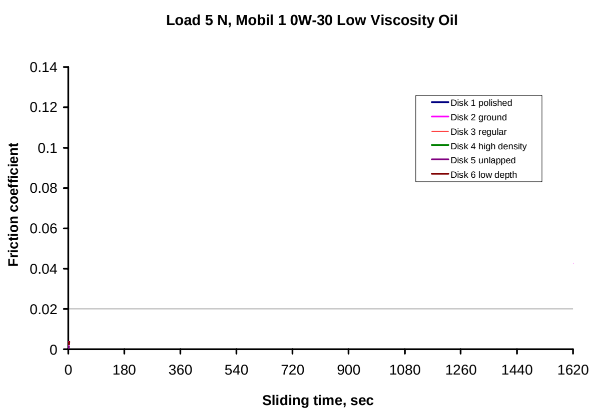

Figure 6. Variation of friction coefficient with time (and velocity) in test with discs having different surface treatments.

The friction behavior for other dimpled and polished discs also shows the same trend, but with much lower magnitudes at the low sliding speeds. This finding suggests that microdimpling either reduces the magnitude of the boundary regime friction coefficient or shifts the operating condition for boundary lubrication to lower speeds. The operating mechanism requires further study.

Discussion

Results obtained so far from seal testing have indicated that laser dimpling of face seals can substantially lower torque, but at the same time it may lead to a slight increase in wear. This is perhaps due to the dimpled surfaces becoming somewhat more vulnerable to micro-fracture and hence wear. The sharp edges of dimples may occasionally cut into the counterface inserts and thus cause higher wear on these surfaces, as shown in Table 1. The exact mechanisms may be much more complicated than speculated here. To overcome these problems, we are currently applying low-friction coatings like NFC on laser textured seal faces. These NFC-coated seals will soon be tested for both torque and wear reduction at Western Michigan University.

Results of the lubricated steel testing for laser-textured surfaces showed that the technology has good potential to reduce friction in components currently operating under the boundary lubrication regime. If the friction reduction is accomplished through the expansion of the hydrodynamic operating regime, it can provide means for engineers to optimize their designs for effective lubrication by incorporating LST on one of the contacting components.

Conclusions

Studies to date have confirmed that laser dimpling has a beneficial effect on the performance of SiC seal faces. Specifically, dimpling substantially reduces torque and thus can increase energy efficiency of electrical motors used in pumps. Laser dimpling causes a slight increase in wear, but we feel that this problem can be reduced or eliminated by applying a low-friction carbon film, such as NFC, on these surfaces. For oil-lubricated steel surfaces, LST reduced the friction significantly under contact conditions of high-friction-boundary lubrication.